CMC Research at NASA Glenn in 2015: Recent Progress and Plans

Joseph E. Grady
Ceramic & Polymer Composites Branch

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Outline

- CMC Development
- Subelement Testing & Failure Characterization
- CMC / EBC Durability Modeling & Validation
- Environmental Barrier Coatings
- Additive Manufacturing

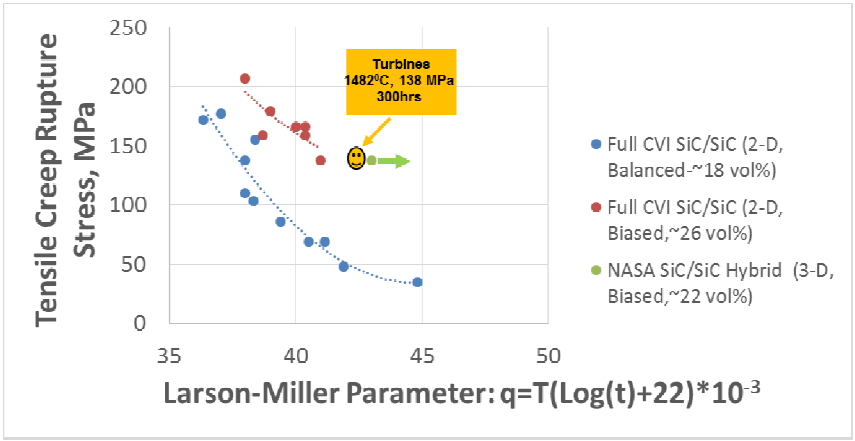
2700^{0}F CMC Development and Characterization

Objective: Develop durable 2700^{0}F CMC for turbine components

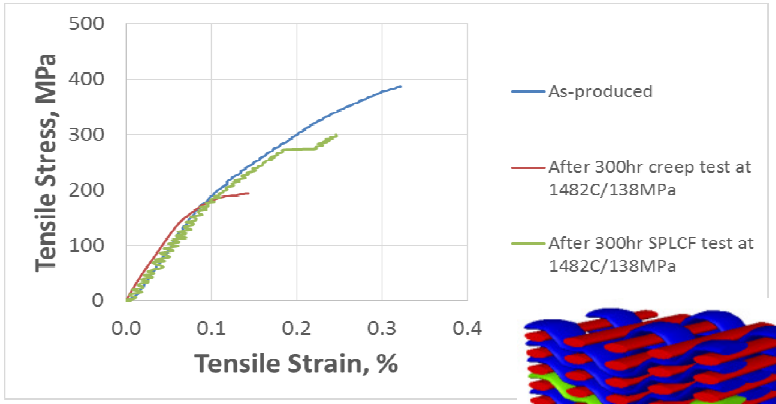
.

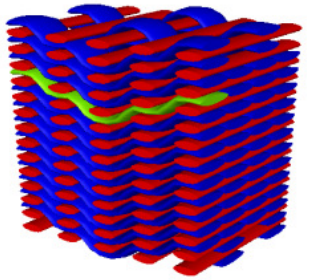
Approach

- Identify optimum constituents and processing methods
- Fabricate 1st generation 2700^{0}F CMC with (CVI+PIP) hybrid matrices and candidate 3D fiber architectures
- Characterize CMC properties and damage mechanisms under static and cyclic conditions for at least 300 hours at 2700^{o}F
- Fabricate 2nd generation 2700^{0}F CMC with optimized fiber architecture and constituents for component applications
- Characterize mechanical properties and damage mechanisms of optimized Gen-2 CMC under static and cyclic conditions.



Generation 1 CMC has >300hrs life at 2700^{0}F / 20 ksi





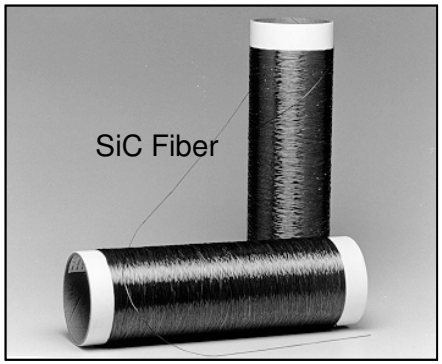
Modified Angle Interlock fiber architecture

Accomplishments

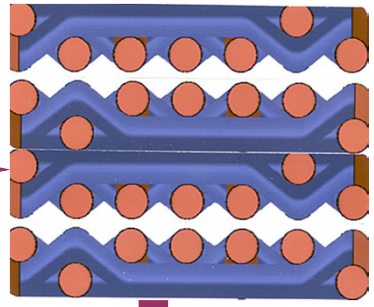
- Demonstrated 20 ksi / 2700^{0}F / 300 hours durability under creep, fatigue and (creep + fatigue) loading for CMC with hybrid matrix and Sylramic-iBN fibers
- Identified optimal fiber architecture (3D Modified Angle Interlock) for Gen-2 CMC with hybrid matrix and Hi-Nicalon-S fibers

contact: ramakrishna.t.bhatt@nasa.gov

Hybrid Process for Dense SiC / SiC Composites



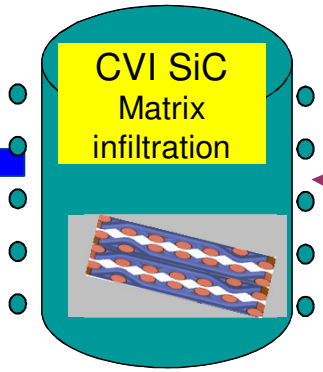
0/90 Fabric
Weaving



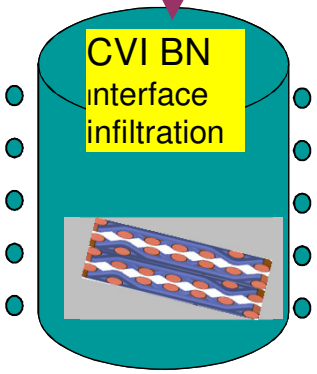
Pre-form by
Fabric Lay-up +
Fabric i-BN
Treatment

CVI BN

Tooling



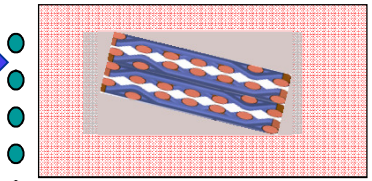
Reactor



Reactor

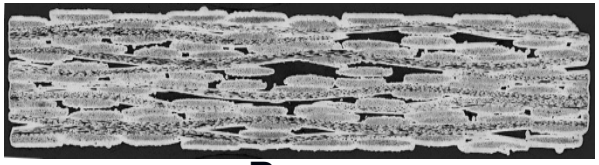
Hybrid matrix combines CVI and PIP processing

Partial CVI



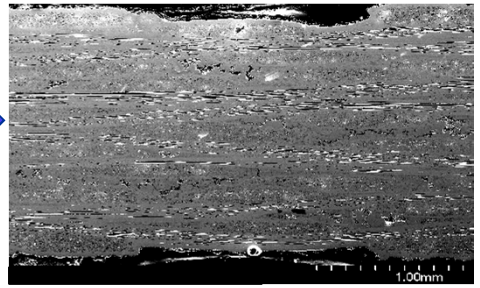
PIP

PIP – Polymer impregnation pyrolysis



Porous

Dense, Si-free composite



Fabrication Process for 2700°F Fiber

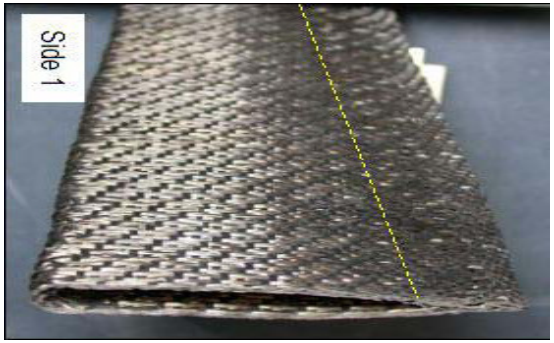
Boron-Sintered SiC Fiber Preform
(formed from commercial "Sylramic" Fiber)

→

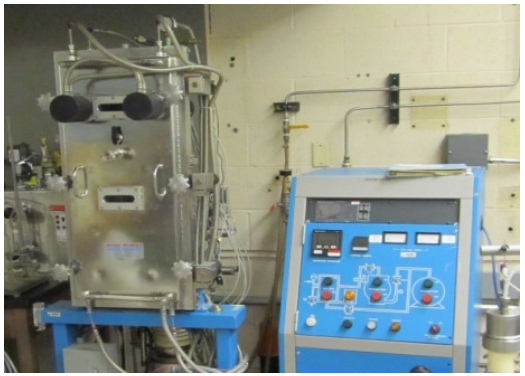
Preform Treatment in High-Pressure N_2
(Boron removal for SOA creep-rupture resistance)

→

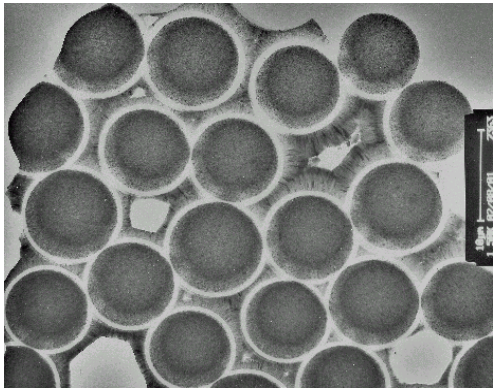
Super Sylramic-iBN Preform
(in-situ grown BN surface layer on each fiber for environmental protection)



Blade Preform



Preform Treatment Furnace



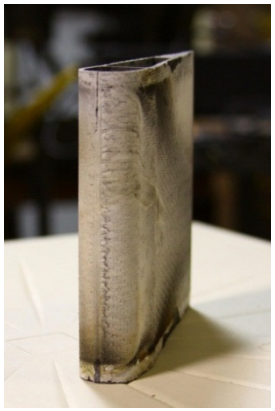
iBN coating between every fiber

Heat treatment in high-pressure N_2 improves creep resistance of Sylramic iBN fiber

US Patent 7,687,016: *Methods for Producing SiC Architectural Preforms*

Rig tests in simulated engine environments evaluate durability of CMC turbine vane subelements

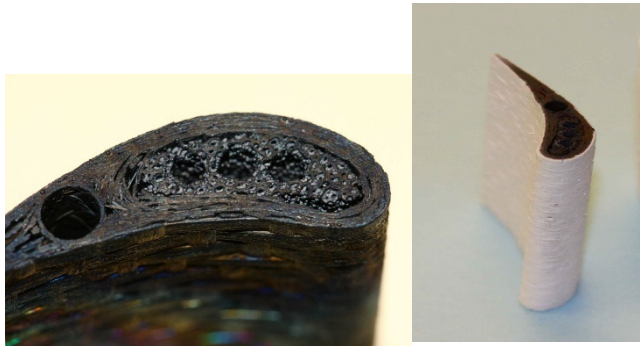
21 hours



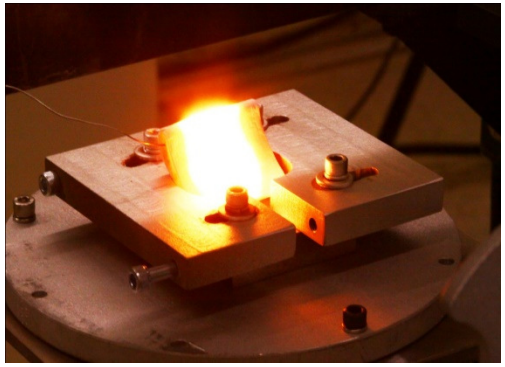
31 hours

70 hours

CVI SiC/SiC vane after burner rig testing
at 2500°F coating temperature
240 m/s gas velocity at 10 atm



CVI SiC with Sylramic iBN

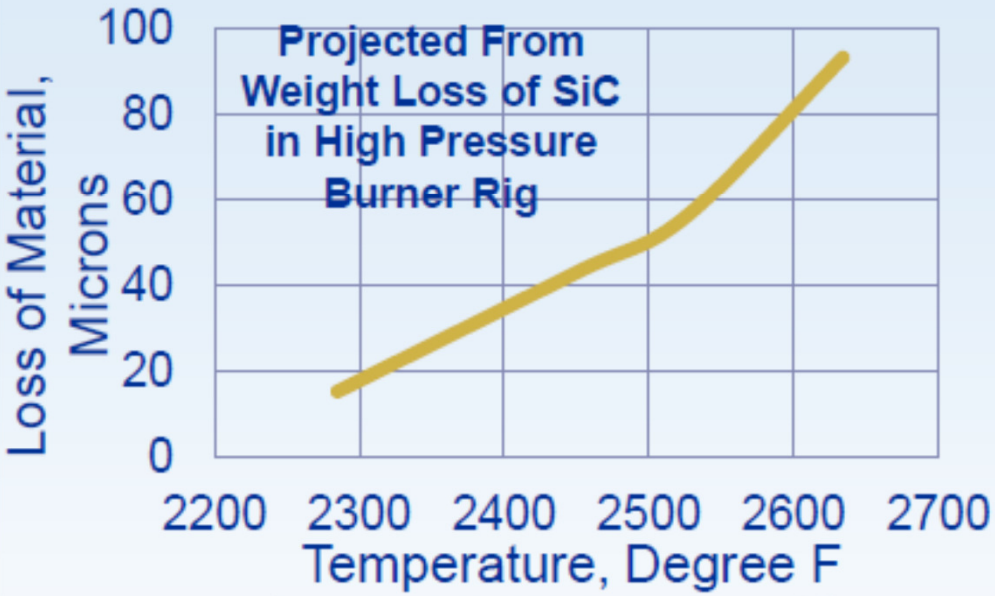


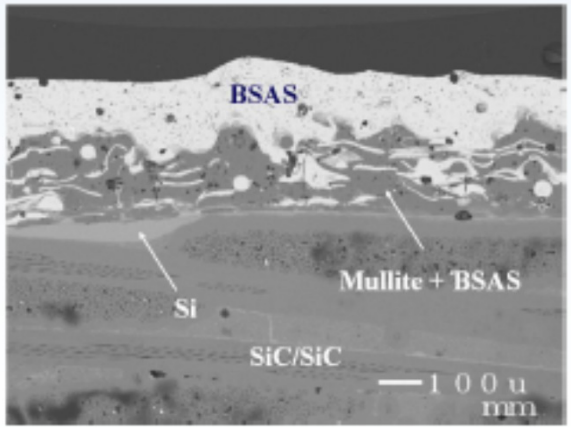
Laser Heat Flux
Thermal Gradient Test

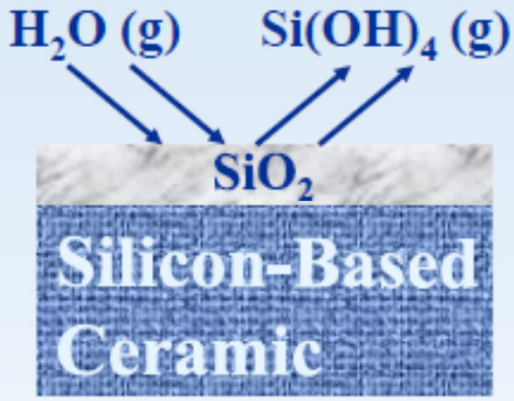
- Completed 1000, 1-hour cycles with 2660°F T_{LE}
- Observed minor damage to leading-edge EBC at 350 cycles

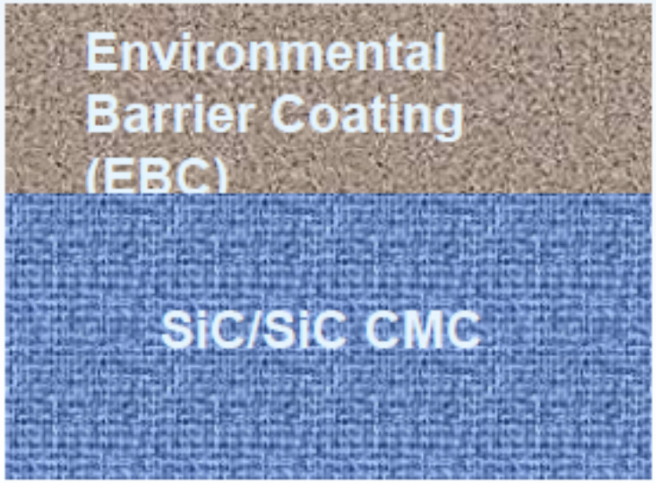
Environmental Barrier Coating for SiC/SiC CMC

Recession of SiC After 100 hr







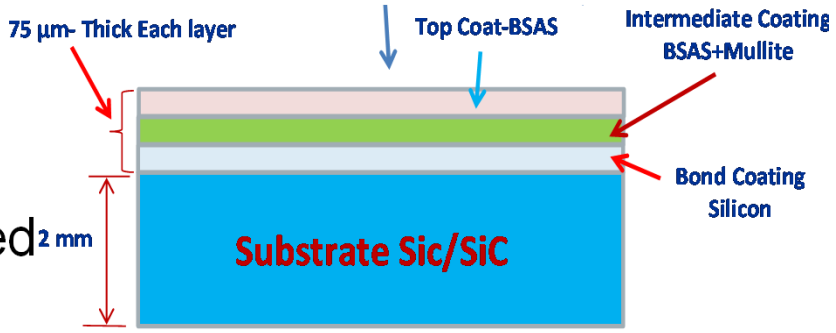


CMC / EBC damage progression modeling & validation

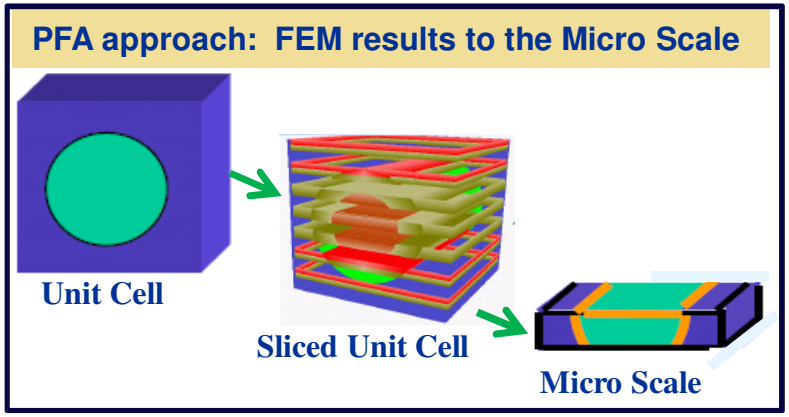
Objective: Model damage accumulation and failure process in EBC/CMC using progressive failure analysis

Approach:

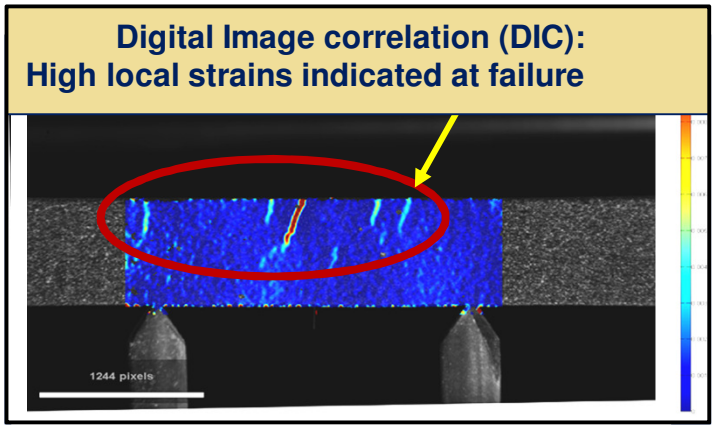
- Select well characterized materials for model EBC/CMC system: plasma sprayed BSAS coating on SiC/SiC substrate



Model System: BSAS-SiC/SiC



- Create FEA model for EBC/CMC using a unit cell representation

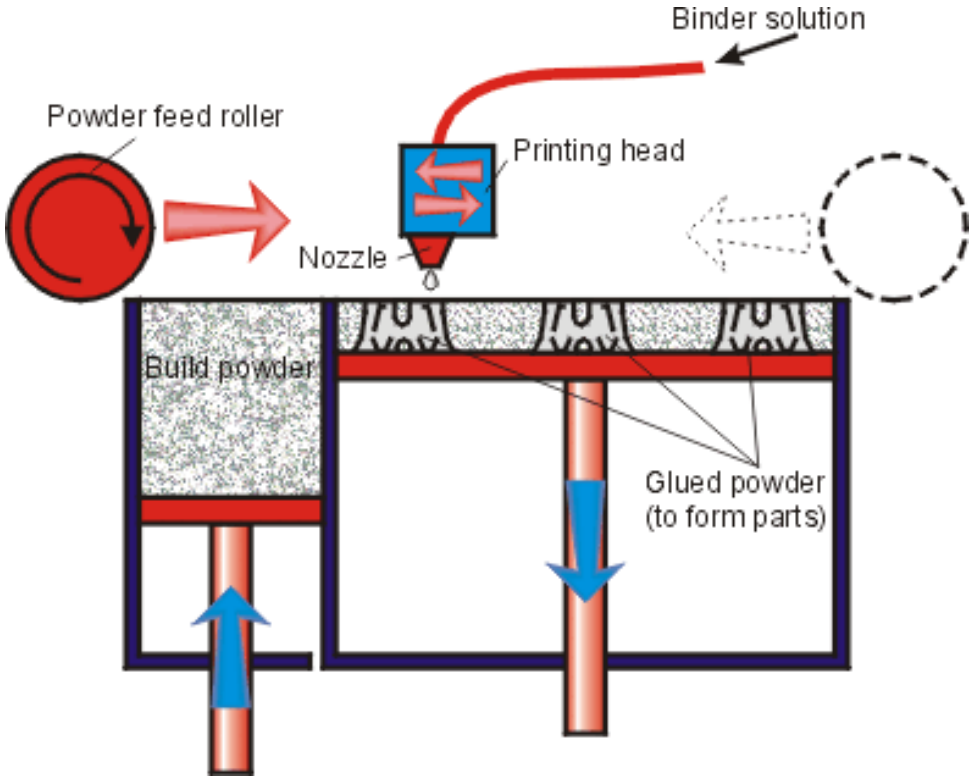


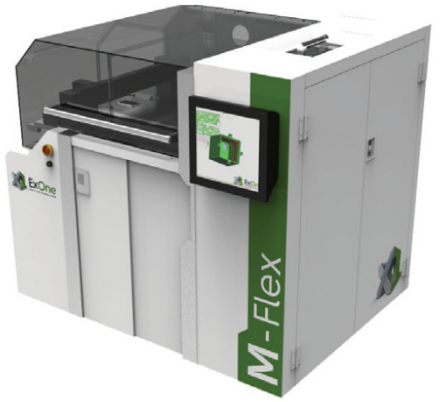
- Validate damage progression results using Digital Image Correlation

contact: martha.h.jaskowiak@nasa.gov

Binder Jet process was adapted for fabricating Ceramic Matrix Composites

An inkjet-like printing head moves across a bed of ceramic powder depositing a liquid binding material in the shape of the object's cross section



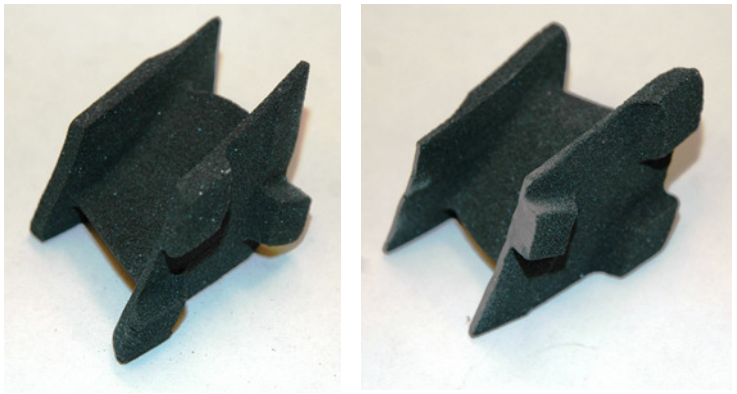


ExOne's M-Flex print machine

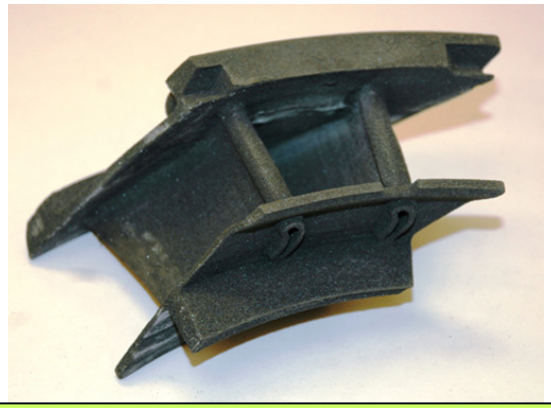
Binder jet printing allows for powder bed processing with *tailored binders* and *chopped fiber reinforcements* for fabricating advanced ceramics

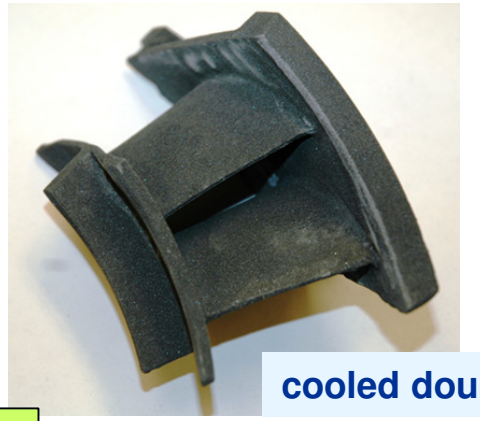
The first CMC turbine engine components by additive manufacturing

high pressure turbine nozzle segments



first stage nozzle segments





cooled doublet nozzle sections

contact: michael.c.halbig @nasa.gov

SiC/SiC CMCs have 20% chopped SiC fiber

CMC Technology Focus in 2015

CMC Development & Characterization

- Optimization of fiber, matrix, and processing for 2700ºF CMC and EBC
- Demonstration of a Process Modeling capability for hybrid CVI / PIP fabrication process
- Further development of high temperature SiC fiber

CMC / EBC Durability Modeling & Validation

- Development & validation of CMC / EBC failure models and life prediction capability

Additive Manufacturing

- Evaluate feasibility of CMC Additive Manufacturing and evaluate suitability of materials for engine applications